US Army Corps of Engineers®
Cold Regions Research & Engineering Laboratory

Ice Engineering

U.S. Army Engineer Research and Development Center, Hanover, New Hampshire

Ice Engineering Facility

The Ice Engineering Facility (IEF) is a unique hydraulic research facility located at the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, part of the Corps of Engineers' Engineer Research and Development Center (ERDC). IEF houses three coldrooms for sophisticated modeling of hydraulic processes in cold regions. The design and operating philosophy of the facility is to provide system flexibility for maximum capability in solving cold regions engineering problems, including ice jams, ice management at locks and dams, vertical and horizontal ice forces on riverine and marine structures, performance of vessels in riverine and sea ice, ice impact on shorelines and the environment, ice effects on sediment movement, and ice effects on fish. Some features and recent research examples are described below.

Research Area

Detailed scale models of lakes and rivers can be built and operated in this 80- × 160-ft refrigerated room to simulate ice interaction with proposed engineering projects. Ambient temperature can be controlled as low as –20°F.

A basement reservoir sends water to the model area using any combination of four pumps with capacities of 450, 900, 1800, and 3600 gpm. Closed loop controls with a magnetic flow meter and frequency drive are used with the 450- and 1800-gpm pumps to maintain a narrow discharge tolerance.

Water temperature can be closely controlled to provide constant water temperatures if desired. Localized cooling can be provided by connecting cooling panels into a refrigerated glycol loop.

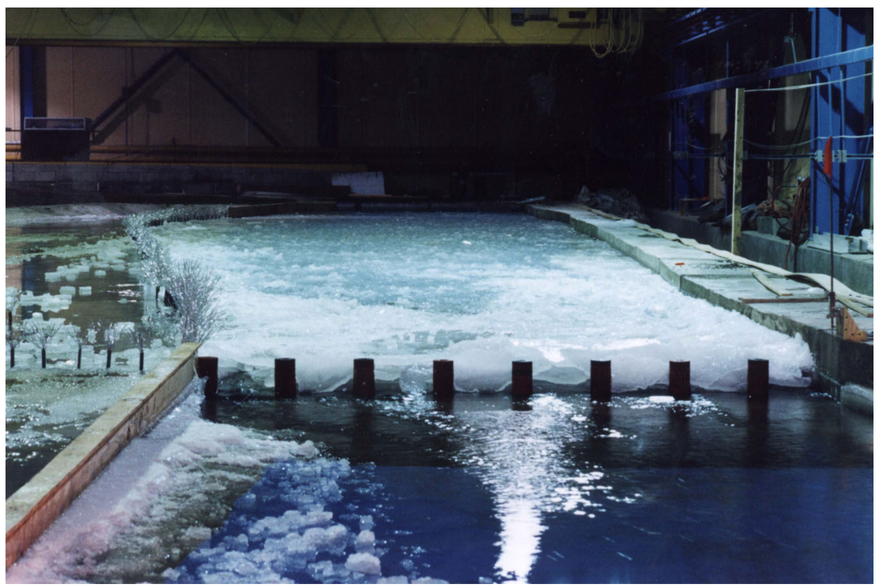

Figure 1. Ice control structure designed and tested in Ice Engineering Facility.

An X–Y bridge crane in the work area has a 2.5-ton capacity with variable speed in the X (160-ft) direction and a personnel platform that allows detailed measurements with minimal flow disturbance while the model is operational. A LABVIEW data acquisition system is used with a variety of sensors to monitor water temperature, velocity and depth of flow, ice forces on structures, bed, and banks, and other pertinent variables. Video and still photography and Web cameras are available to provide visual documentation.

Recent tests have focused on designing low-cost ice control structures (ICS) to mitigate ice jam flooding by retaining ice upstream of the impacted area and minimizing the effect of ice on the operation of navigation structures.

The goal of an ICS is an environmentally friendly structure that reduces flood damages and has a low life-cycle cost. Figure 1 shows the proposed ICS designed and tested for Cazenovia Creek in New York, a study done in support of a Section 205 study conducted by the Buffalo District. Observations and measurements from physical models were used to develop and verify complex numerical simulations. Once verified, the simulation was used to optimize structure configuration for capture

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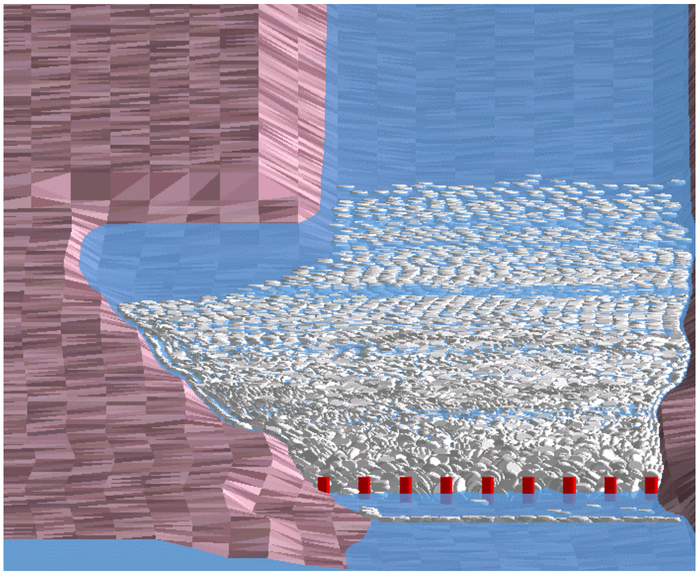

Figure 2. Graphical image of Cazenovia Creek ICS generated by numerical simulation.

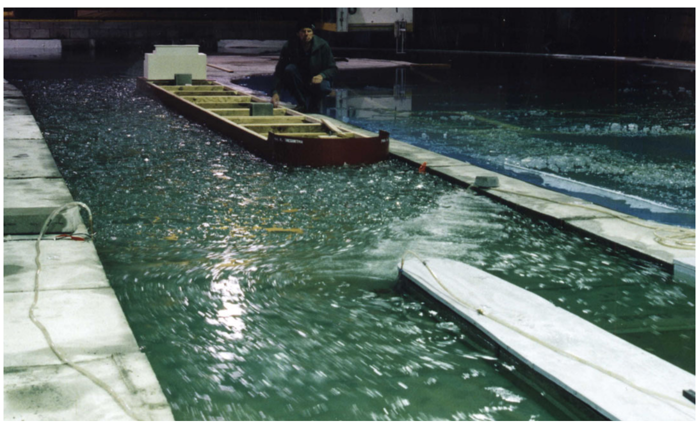

Figure 3. Model of navigation locks, Sault Ste Marie, Michigan, with bubbler system operating.

efficiency and to quantify design loads. Optimal designs were evaluated using the physical model. This iterative process provides a high return on research investments. Figure 2 shows a graphical image generated by the numerical simulation of the Cazenovia Creek ICS.

Ice increases ships' transit time through locks, thus increasing time and money costs substantially. Various ice passage methods, including bubbler systems, submerged gates, ice passageways, etc., have been tested in IEF's Research Area (Fig. 3).

Other tests include ice jam mitigation using ice retention weirs, ice control structures, and floating booms; performance and optimization of thermosyphons designed to keep permafrost frozen under engineered structures; and ice adhesion on structures. The Research Area is also used to evaluate performance of equipment in cold environments, including power generation, sensors, and snowmaking systems.

Flume

The recirculating flume is a basic research tool for investigating frazil ice, ice jam effects on river ice hydraulics, and sediment transport processes under ice covers. The 2-ft-deep × 4-ft-wide × 120-ft-long flume can be tilted from +2° to –1° slope and is in a coldroom that can be refrigerated to –20°F. As in the Research Area, temperature-controlled water is stored in a reservoir in IEF's basement. Water is drawn from the reservoir using one of two rubber-lined impeller pumps having capacities of 1800 gpm and 4050 gpm. A closed-loop control system consisting of a magnetic flow meter and process controller maintains a tight tolerance on the smaller pump discharge.

As in the Research Area, the closed-loop control system pump can maintain a constant discharge or follow a computer-generated hydrograph. For frazil ice studies, which require supercooled water, flow is redirected to a supercooling ramp prior to entering the flume. As the supercooled water enters the flume, it passes a computer-controlled spray nozzle generating ice crystals that seed the frazil ice. Because the generation of turbulent supercooled water and subsequent frazil ice rarely occurs in flumes this large, it is a valuable research tool.

An X-Y instrumentation carriage facilitates computer-controlled data collection. The carriage is driven along the length of the flume (X axis) by rack and pinion with independent position registration. A screw-driven slide assembly on the front of the carriage positions instruments across the flume (Y axis). Mounted instruments can take repeated measurements automatically at any point along the flume. For sediment studies, an automatic non-contacting bed follower is mounted to the Y-axis to contour the sand surface (Fig. 4).

Another feature of the flume is a refrigerated bed that facilitates aufeis formation studies and other unusual conditions that require physical modeling. A sinusoidal wave maker can be used to investigate wave effects on hydraulic processes in cold regions. The flume is equipped with a LABVIEW data acquisition system that interfaces with a variety of sensors to monitor test variables, position the instrumentation carriage, and other input/output capabilities as required to customize data acquisition to meet project needs. This system also has pattern recognition, which is useful for tracking ice movement in laboratory and field studies. A 2.5-ton monorail crane is available to move test apparatus and material into the flume.

The flume has been used to study evolution and control of frazil ice and sediment transport. CRREL worked with the University of Waterloo to assess effects of frazil ice on trout. The investigation monitored the fish's vital signs as frazil ice was generated and accumulated in the flume. The fish's activity levels in open reaches of the flume were monitored through surgically implanted electromyogram (EMG) radiotransmitters as well as surface and underwater video cameras.

Stress response was measured in fish confined to cages. Each cage contained one fish tethered to instrumentation that monitored cardiac output from ultrasonic Doppler flow probes placed around the ventral aorta. The tests were the first of their kind and proved invaluable for establishing the physiological reactions of fish to frazil ice, which occurs in open water during extremely cold periods.

The wave-making capability was used in joint research with Clarkson University to develop a correlation between wave characteristics (period and amplitude) and the production and accumulation of frazil ice.

The flume also is used to investigate accelerated bed degradation caused by ice covers and ice jams, and scour around bridge piers. Other work includes controlling frazil ice blockage of trash rack water intakes, ice jam internal forces, and open channel tests requiring controlled water or air temperatures.

Figure 4. Non-contact bed profiler.

Test Basin

The Test Basin is used to conduct large-scale studies of ice forces on structures such as dams, piers, ships, and offshore platforms. The 120-ft-long × 30-ft-wide × 8-ft-deep tank is housed within a coldroom that can be refrigerated to –20°F. The tank is typically filled with 1% urea water, which allows the engineering properties of the ice to be scaled to correspond to the physical scale of the model. Freshwater and seawater also have been used.

At –20°F, a 2-mm-per-hour ice growth rate can be achieved. For most tests, desired ice thickness can be achieved overnight at this rate. For special projects, 12-inch-thick ice has been grown in just over a week. Bubblers ensure that the water column is isothermal to maintain uniformity of ice characteristics between ice sheets. Ice can be frozen to the walls to simulate continuous cover or, using wall heaters, a free-floating cover.

A set-up pool, or prep tank, can be thermally isolated from the rest of the basin, allowing the model to be prepared while the ice sheet is forming. At the opposite end of the tank, the end wall is sloped and serves as an entrance ramp to help push the broken ice into the melt tank at the end of the test. Once the ice is cleared, another ice sheet can be seeded and grown while the debris ice from the previous tests melts. The rapid turnaround of growing, testing, and clearing permits multiple test iterations each week. This shortens the test period, thus maximizing the benefit of the research investment.

Test structures or models are suspended under or pushed through the ice by the main carriage. The drive train includes a variable frequency drive motor, a two-speed transmission, and rack and pinion final drive. Carriage speed range is 1-in./sec to 7 ft/sec with 1000-lb load capacity for all axes. A high-force module that can be attached beneath the carriage has a screw drive with a 10,000-lb load capacity for all axes. A second tire-mounted personnel carriage is used to calibrate the ice sheet with plate deflection and cantilever beam test as well as prepare the water surface for seeding the ice cover. Both carriages are connected to utilities (electrical, computer network, and fixed instrumentation) by a festoon system. The ice-structure interactions dictate high-speed data acquisitions with a sample rate of 19.2 kHz. This system monitors the output of force, pressure, and distance transducers used in the test configuration. Underwater lights and cameras in combination with surface video and still cameras document the tests. A 2.5-ton monorail crane is available to move equipment into the basin.

Recent tests include a study to develop design criteria for riprap-protected shorelines exposed to ice action. Test variables included stone-size distribution, ice thickness, riverbank slope, and bank orientation with respect to the impacting ice. Two model shorelines were mounted on a wheeled platform resting on the tank bottom, which was pushed into the ice by the main carriage (Fig. 5).

The Test Basin also has been used to conduct model studies of icebreaking vessels, including NSF's *Nathaniel B. Palmer* and Coast Guard icebreakers. Model studies quantify icebreaking and maneuverability of the vessels in level and brash ice. Other tests include ice forces on structures (vertical, horizontal, and impact), forces required to penetrate an ice cover, long-term loading of ice, creep deformation, and debris loading on structures. The test basin has been used to grow ice that is harvested and used by other on-site and off-site research programs. To evaluate the performance of a model amphibious all-terrain escape vehicle, an ice-covered obstacle course was constructed in the basin.

Figure 5. Test Basin.

Refrigeration System

IEF's refrigeration plant is relatively small compared to those in the food processing and cold storage industry. What sets this plant apart is the dynamic operation dictated by the test schedule. Unlike ordinary refrigeration systems, where required room temperatures are constant, temperatures in IEF's coldrooms are cycled independently from cold (–20ºF) to warm (25–38ºF) as often as every six hours. Performance of the system and the environment within the respective coldroom is documented using a Supervisory Control and Data Acquisition (SCADA) System.

Air is cooled by recirculating liquid ammonia through ceiling-mounted air units in the coldrooms. Water is cooled by using submerged coils and is heated with in-line heat exchangers. For maximum efficiency, waste heat from the refrigeration cycle is recovered and used to heat IEF's offices and work areas, and to melt ice and heat water.

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This issue of Ice Engineering *was written by Leonard J. Zabilansky, Civil Engineer, Ice Engineering Team, Engineering Resources Branch, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Engineer Research and Development Center (ERDC), Hanover, New Hampshire. The work was funded by Civil Works Cold Regions Engineering Program Work Unit CWIS #33202, Characterizing Ice Impacts on Operation and Maintenance.*

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